Pulsed Sextupole Injection for Beijing Advanced Photon Source

Yi Jiao

Institute of High Energy Physics, CAS

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中國科學院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

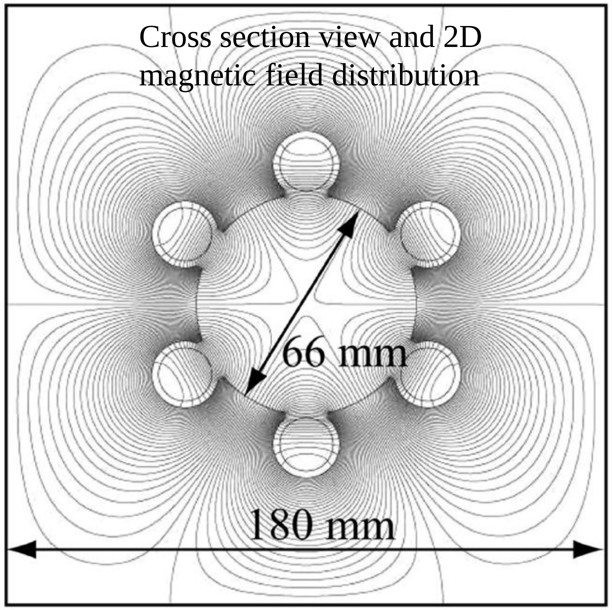
Brief History

- The Photon Factory Advanced Ring (PF-AR) at KEK, Japan, successfully designed and commissioned pulsed sextupole magnet (PSM) in 2010.

- **Pulsed sextupole injection (PSI) can evidently reduce the dipole oscillation amplitude and improve the performance of the light source with "top-up" injection scheme.**

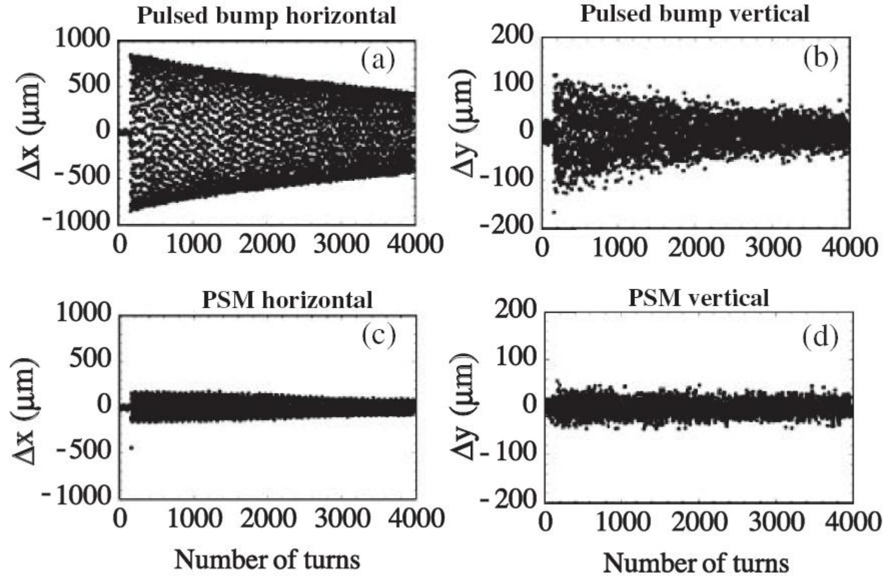
- **Typical contributions:**
- Y. Kobayashi, and K. Harada, EPAC2006, THPLS107
- H. Takaki, *et al.*, PAC07, MOPAN034
- H. Takaki, *et al.*, Phys. Rev. ST Accel. Beams **13**, 020705 (2010)
- C. Sun, *et al.*, IPAC10, WEPEA068
- X.R. Resende, *et al.*, IPAC11, THPC139
- S.C. Leemann, Phys. Rev. ST Accel. Beams **15**, 050705 (2012)
- …

Pulsed Sextupole Injection in KEK PF

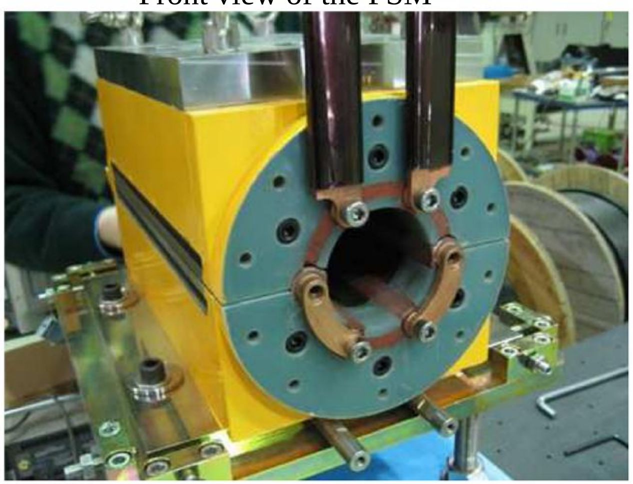


Cross section view and 2D magnetic field distribution

Beam oscillations of the stored beam immediately after injection



Front view of the PSM

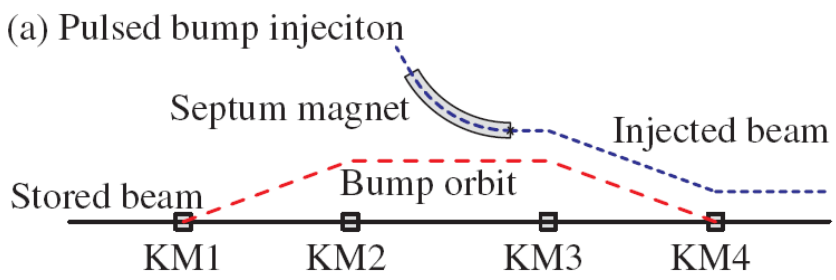


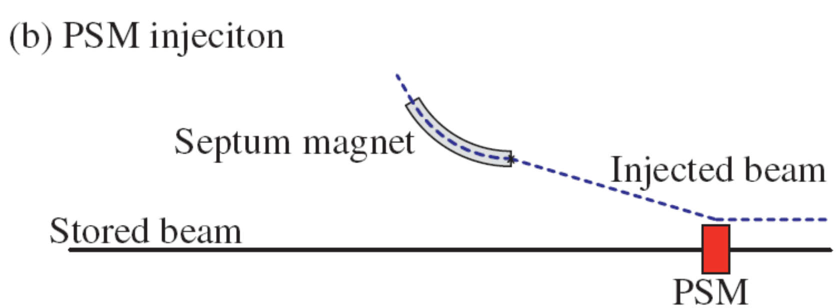
Installation of PSM in the PF ring

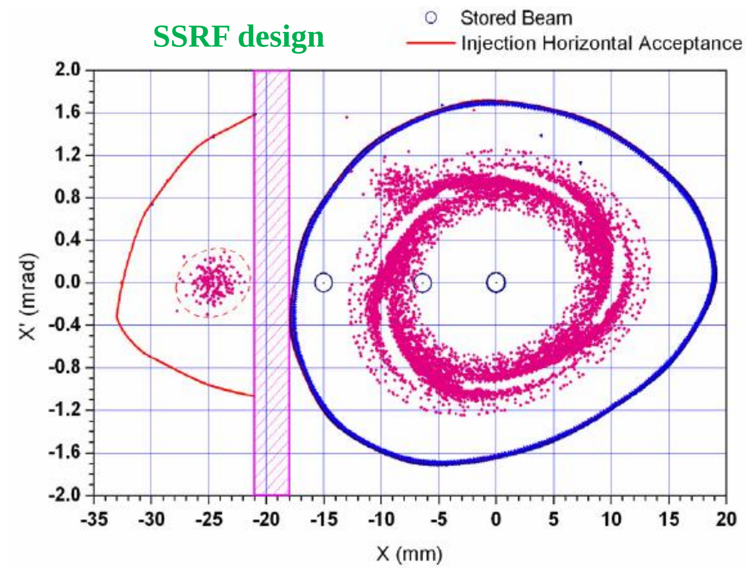
H. Takaki, *et al.*, Phys. Rev. ST Accel. Beams 13, 020705 (2010)

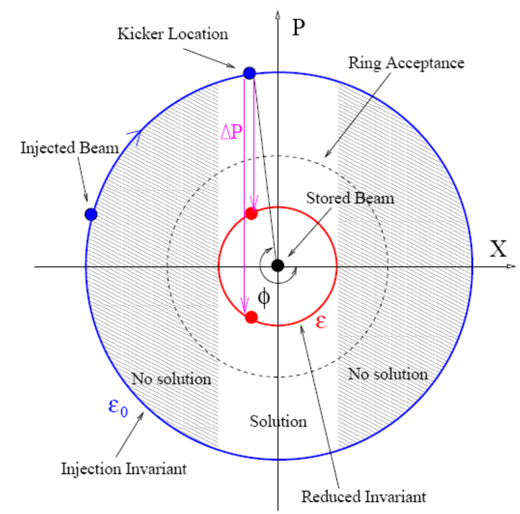
Principle

- **PBI (using kicker magnet) vs. PSI (using pulsed sextupole magnet) in electron storage rings**









Principle

Injection emittance (at septum)

in terms of normalized coordinates

$$\varepsilon_0 = \left(\frac{x_0}{\sqrt{\beta}}\right)^2 + \left(\frac{\alpha x_0 + \beta x_0'}{\sqrt{\beta}}\right)^2 = X_0^2 + P_0^2$$

Injection emittance (at PSM, before kick)

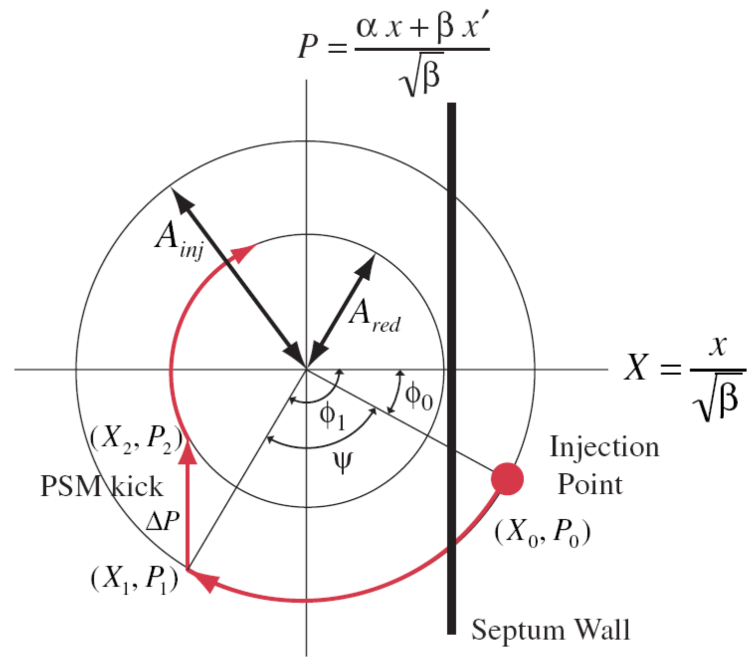
$$X_1 = X_0 \cos\phi,$$
$$P_1 = P_0 \sin\phi,$$
$$\varepsilon_1 = X_1^2 + P_1^2 = \varepsilon_0.$$

If considering only linear optics

Reduced emittance (at PSM, after kick)

$$X_2 = X_0 \cos\phi,$$
$$P_2 = P_0 \sin\phi + \Delta P,$$
$$\varepsilon_2 = X_2^2 + P_2^2.$$

ϕ is the phase advance between the septum and the PSM



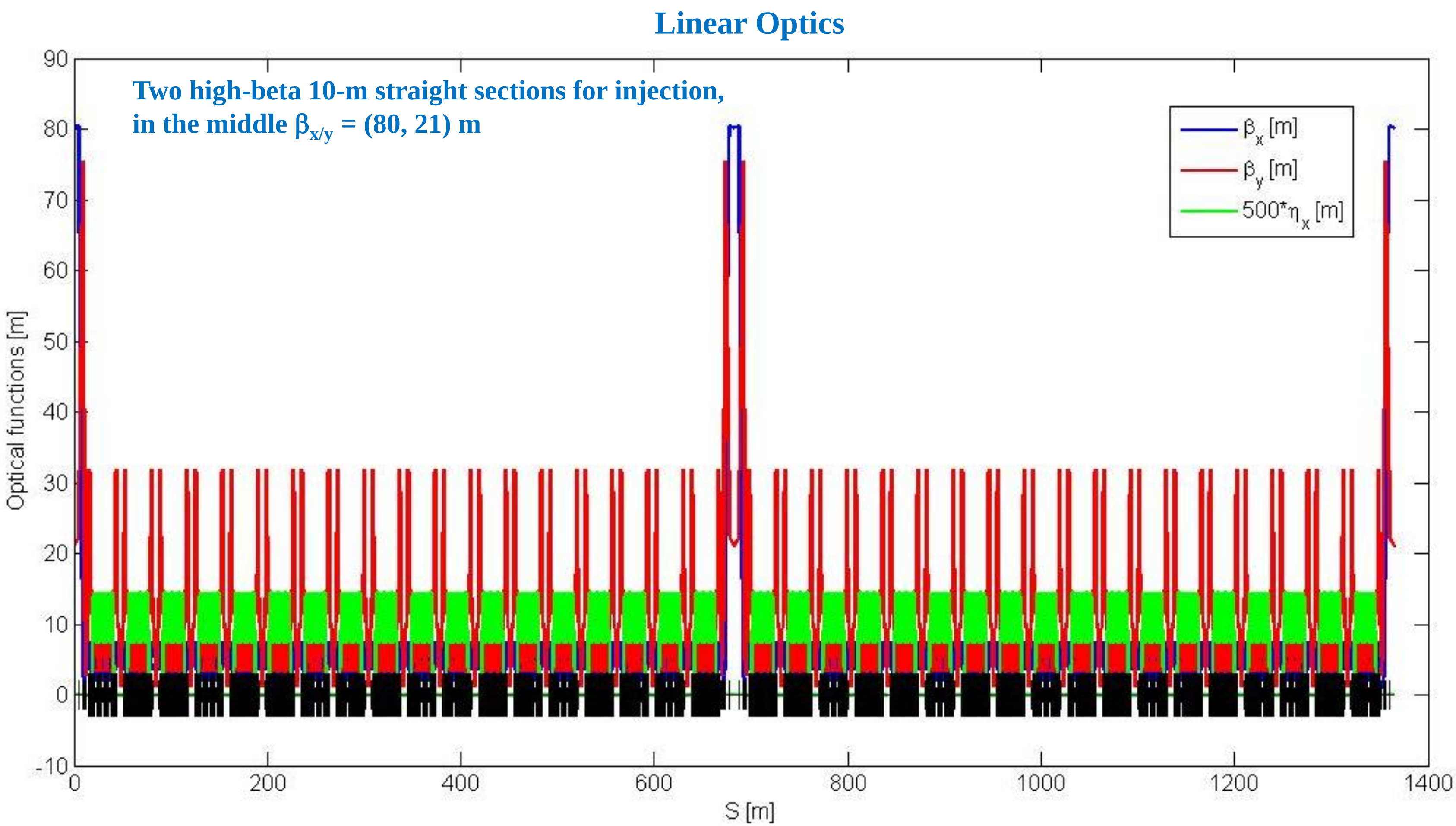
To ensure the beam is accepted by the ring, the reduced emittance should be smaller than the ring acceptance

$$\varepsilon_2 < \varepsilon_{acc} = \frac{x_{acc}^2}{\beta}$$

The kick of the PSM

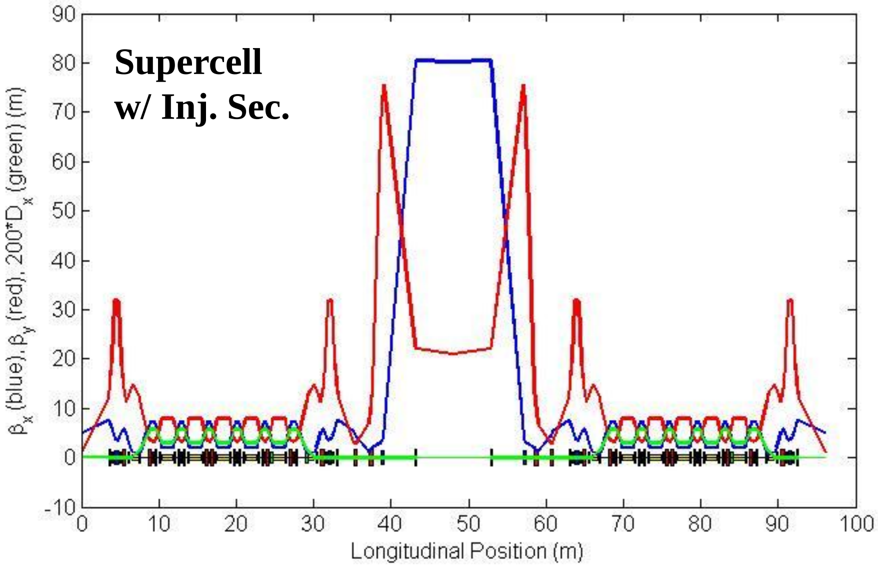
$$\Delta P = \sqrt{\beta}\theta = -\frac{1}{2}\beta^{3/2} K_2 X_1^2,\ K_2 = \frac{B''_{sext} L_{sext}}{B\rho}.$$

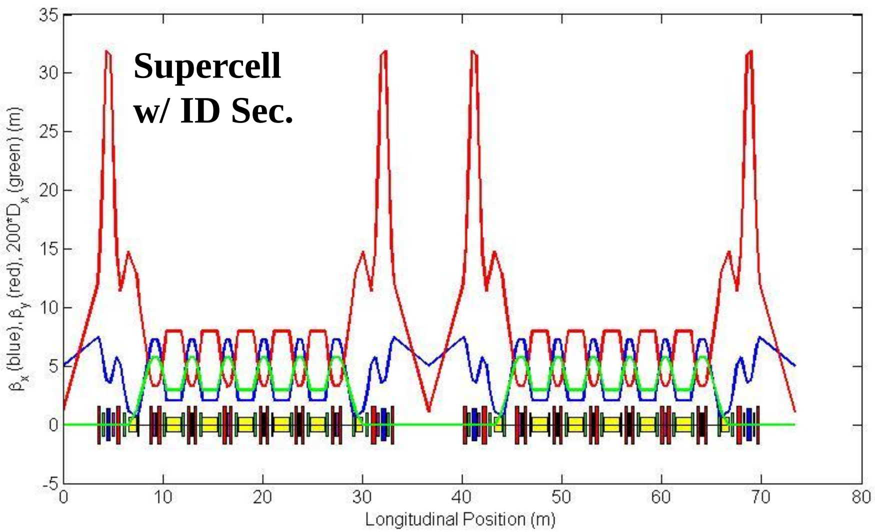
Beijing Advanced Photon Source (BAPS)



Circumference: 1364.8 m, 2 superperiods, 36 supercells
Working point: 111.39, 39.30
Natural chromaticity: -184, -181
Natural emittance: 51 pm.rad

Nonlinear Optimization

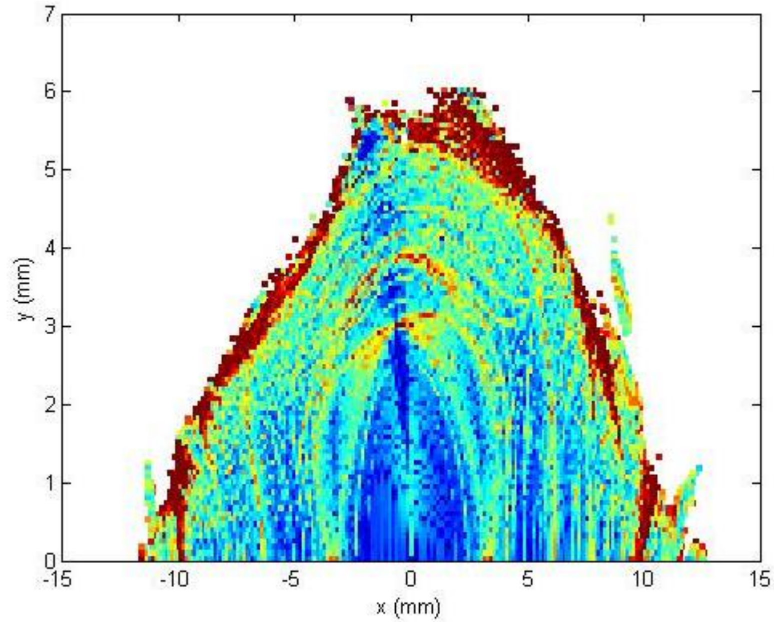




Phase advance (supercell w/ Inj. Sec.) H/V =
Phase advance (supercell w/ ID Sec.) + $2\pi/0$

Every 12 supercells forms a quasi-3rd-order achromat

Large On-momentum DA

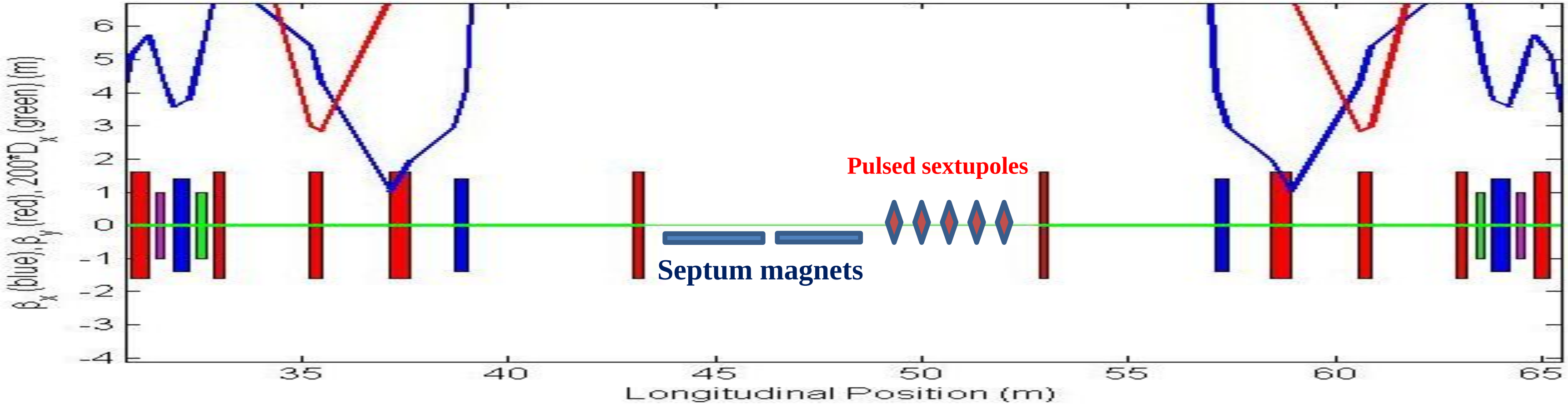


The pulsed sextupole is located in the straight section.

Pulsed Sextupole Injection for BAPS

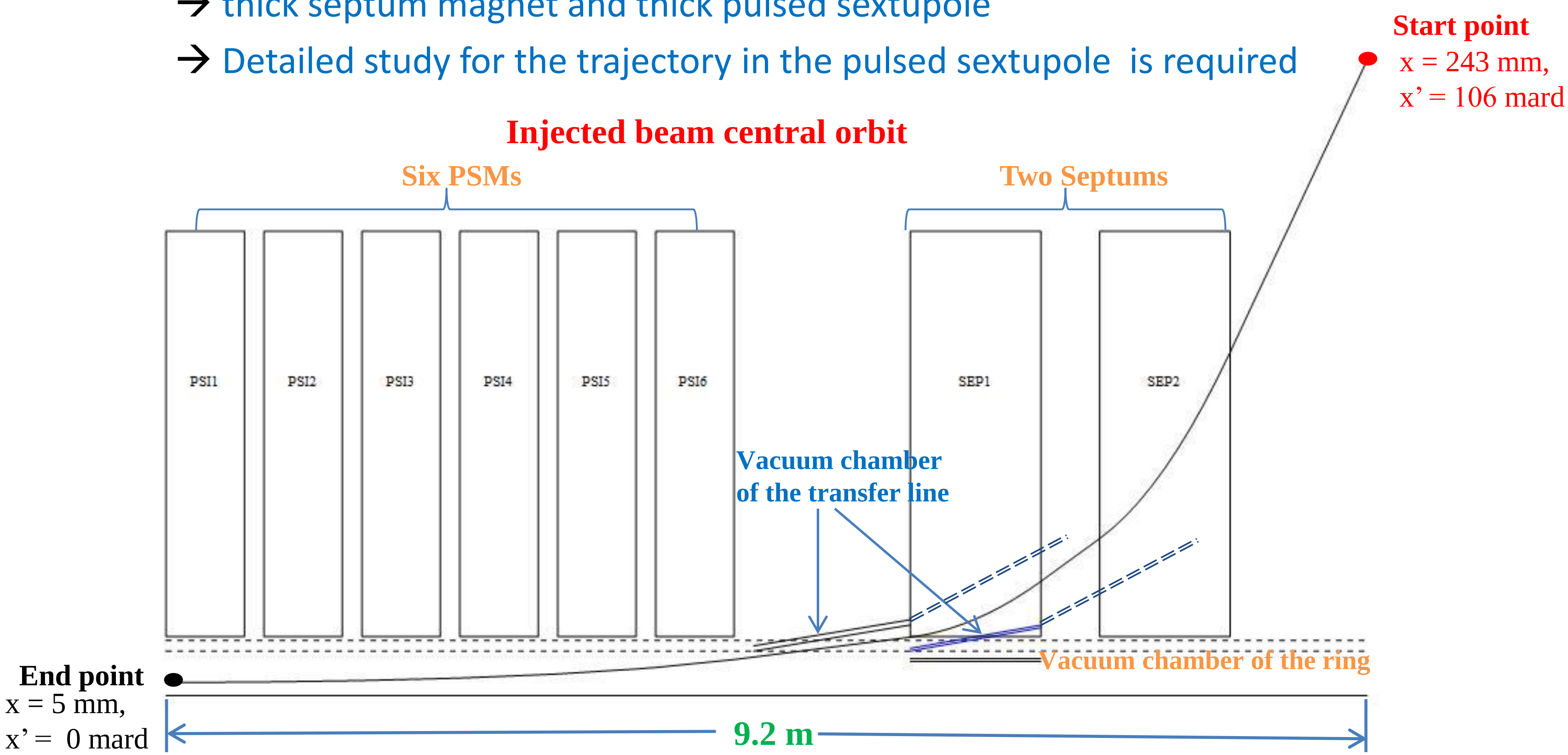
- Injected beam: 4 nm.rad   from booster
- Vacuum chamber half gap: 11 mm
- Injection in the **High-beta 10-m Straight section**, promising moderate sextupole strength.

- **PSI options:**
- **Option 1: Between injection point (end of the septum) and kick point (location of the pulsed sextupole), only drift space.**
- --- If required, needs to use **only a larger-aperture vacuum chamber** in the drift space.
- ---**Small phase advance**, strict requirements for the injection angle and pulsed sextupole strength.



Pulsed Sextupole Injection Option 1

- Large injection angle and large pulsed sextupole strength,
  - → thick septum magnet and thick pulsed sextupole
  - → Detailed study for the trajectory in the pulsed sextupole is required

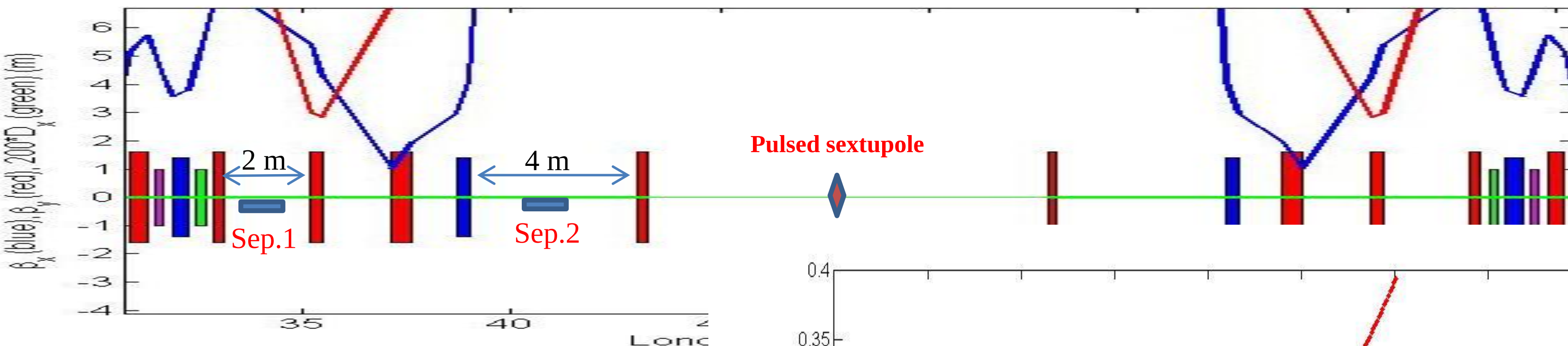


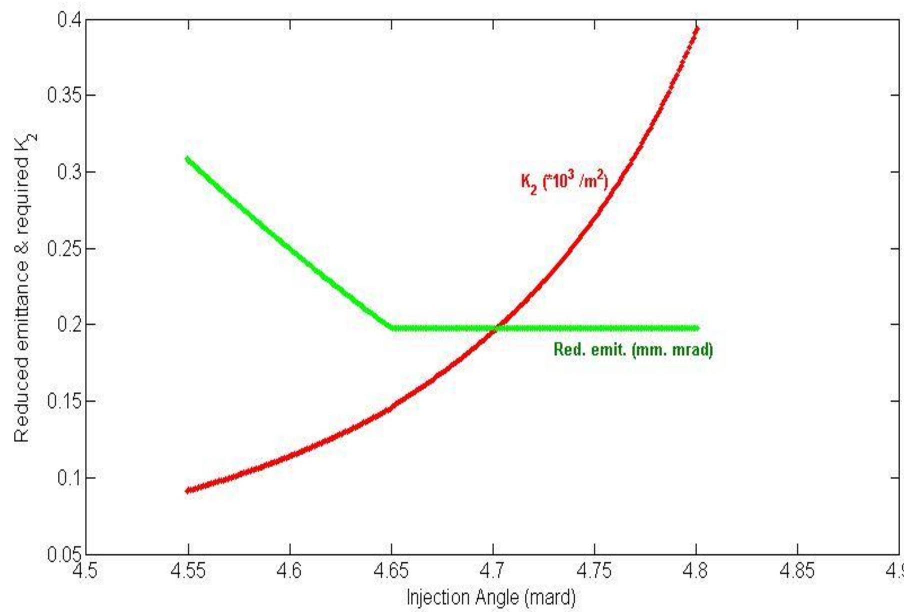
PSM: r = 24mm, L=0.6 m, $k_2 = B''/B\rho = 59.3\ m^{-3}$, $B'' = 1000\ T/m^2$
SEP1: L=1m, angle=30 mrad
SEP2: L=1m, angle=70 mrad
Total mechanical length < 8 m

Courtesy of XU Gang

Pulsed Sextupole Injection for BAPS

- **Option 2: Between injection point (end of the septum) and kick point (location of the pulsed sextupole), a few quadrupoles.**
  - --- It may needs to use a larger-apeture vacuum chamber as well as a few **larger-aperture magnets**.
  - ---The phase advance is relatively large, **less pulsed sextupole strength**.

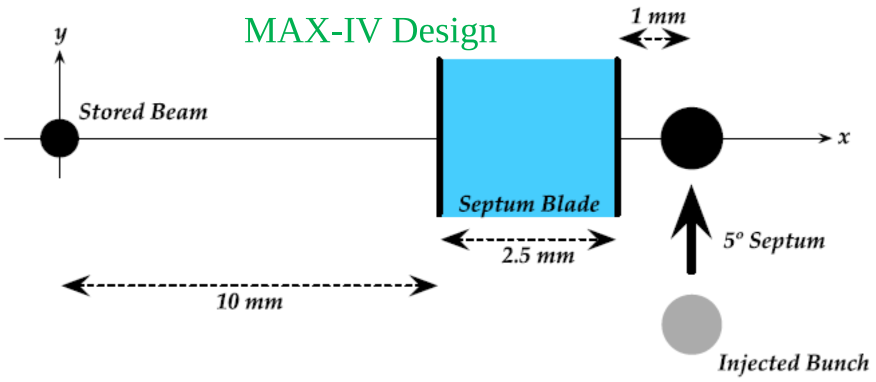




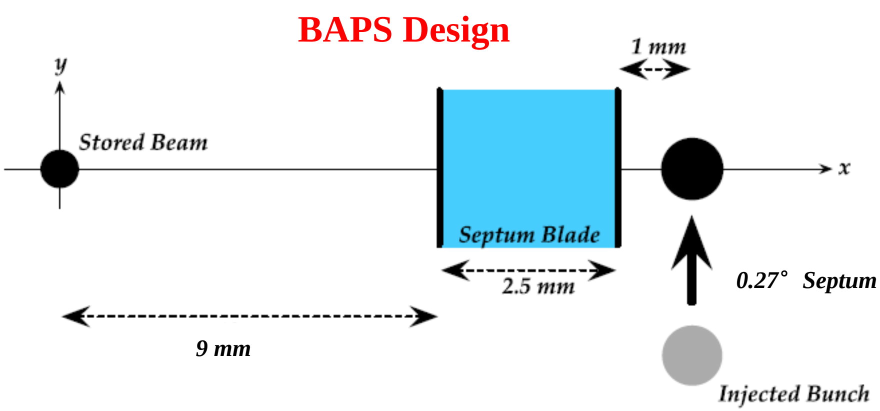
- **Injection with Sep.2, relatively small injection angle (typical angle 1 mard), but large sextupole strength (typical K_2 = 360 m^{-2})**
- **Injection with Sep.1, relatively large injection angle (typical angle 4.6 mard), but small sextupole strength (typical K_2 = 150 m^{-2})**

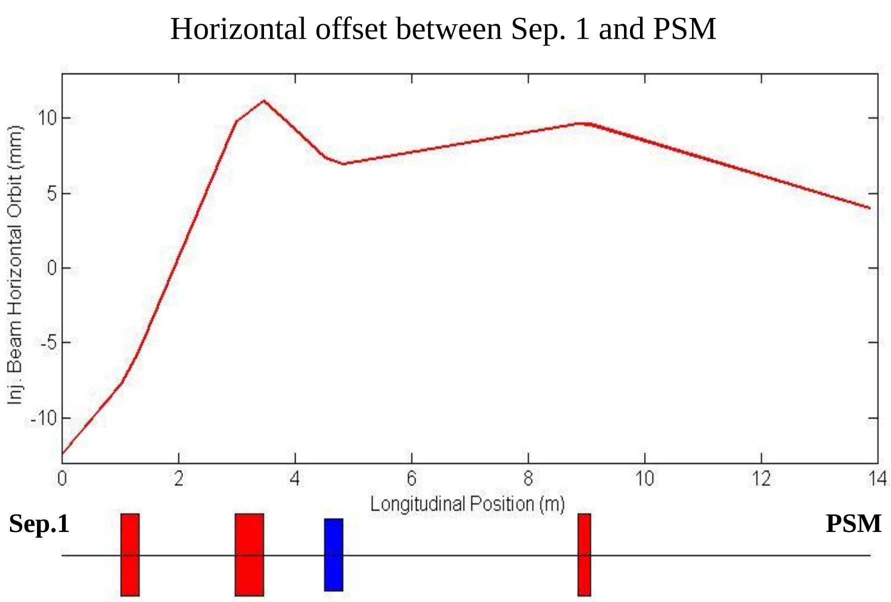
Pulsed Sextupole Injection Option 2

- The injection point is Sep. 1, while the PSM is in the middle of the 10-m drift space.



Initial offset -12.5 mm
Septum magnet, angle = 4.65 mard
Offset at PSM is x = 4 mm
Between septum magnet and PSM, vacuum chamber ~ 26 mm in horizontal plane





Pulsed Sextupole Injection Option 2

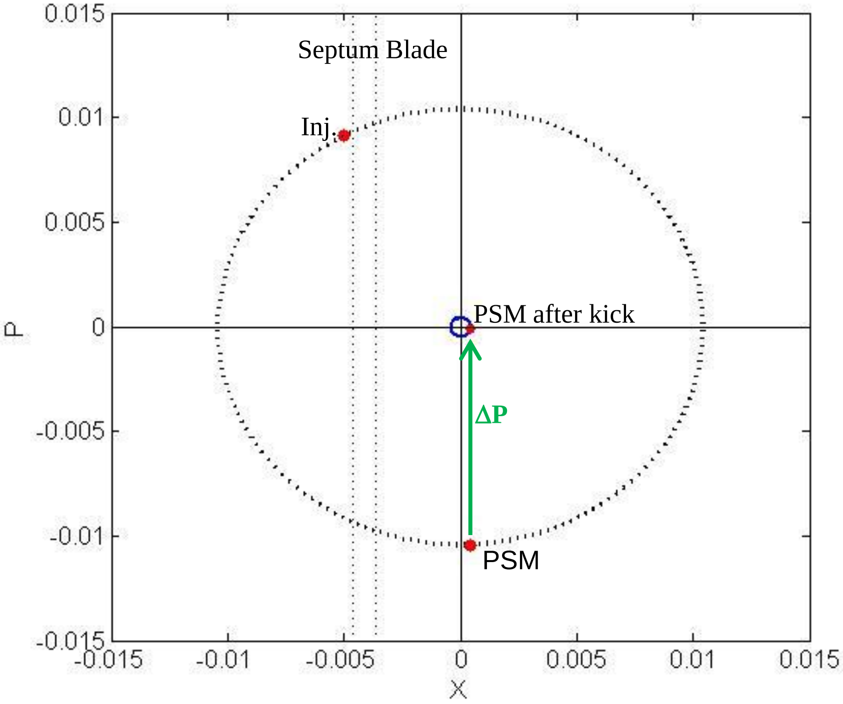
Injected emittance at septum : 108 mm.mrad,
Reduced emittance after kick : 0.2 mm.mrad
Required gradient K_2 : 144 m^{-2}
(KEK PF: 13 m^{-2} MAX-IV: 106 m^{-2})

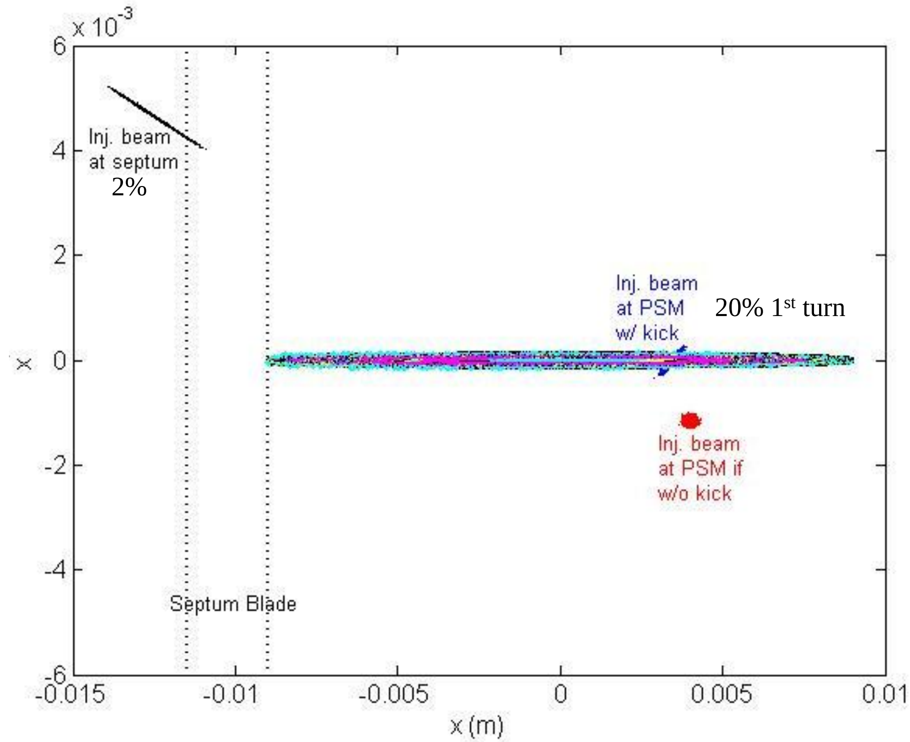
2 m sextupole, 36 mm bore diameter, B'' = 1200 T/m^2, field gradient 1350 Gauss @ x= 15 mm, field gradient 1944 Gauss at pole face @ x= 18 mm.

Large β_x cause large σ_x, and also small acceptance to x', leading to rather low capture efficiency.

Inj. Beam emittance, X/Y = 4 nm.rad, 4 nm.rad*2%.
Matched beam, capture efficiency, ~ 20%.

Unmatched beam, optimal case, capture efficiency ~ 60%.





Summary

- We discuss the possible injection options using pulsed sextupole.
- A large enough dynamic aperture is necessary for and benefits pulsed sextupole injection.
- With septum and pulsed sextupole in one drift space, the required septum and sextupoles strength are strong but feasible. With appropriate phase advance between septum and pulsed sextupole, one can reduce the magnetic strength.
- For pulsed sextupole injection in BAPS, capture efficiency is not high, ~60%.
- Further study is under way.

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